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Performance studies on a novel solar PV/T-air dual heat source heat pump system

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Abstract

A novel solar PV/T-air dual heat source composite heat pump system was developed and the experimental platform was built to research the instantaneous performance. The experimental results show that the maximum instantaneous generating efficiency of solar PV/T collecting circulation of the system could achieve 15.0% and average heat collecting efficiency was 43.8% when average ambient temperature and solar irradiance were 6.5°C and 581.5W/m². Heat distribution average ratio of solar, air and compressor at the run time were 28.1%, 35.7% and 36.2% respectively. Heat pump instantaneous COP changed between 2.0 to 2.6 and the average value was 2.5, which indicated that the system performance was relatively well.

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Keywords: Solar PV/T collector; heat pump; composite exchanger

1. Introduction

The PV technology is a major application method in solar energy utilization technologies. Both domestic and foreign scholars have been carrying out large-scale research works to drop the temperature of PV backboard and improve the photoelectric conversion efficiency [1,2]. The joint operation technology of solar energy and heat pump is another way of utilizing solar, which was first proposed by Jordan [3]. Later many domestic and international

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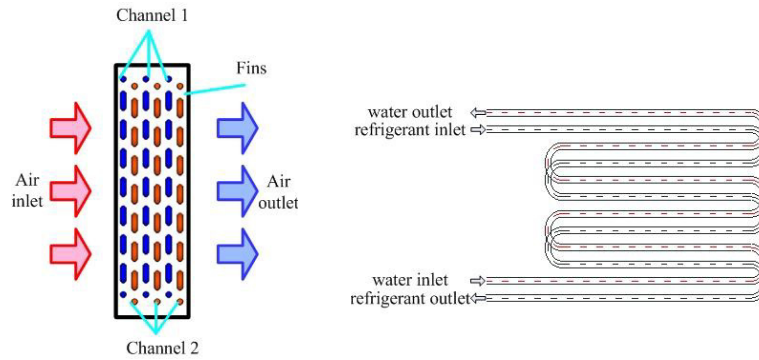


Fig. 2. Structure of composite exchanger

3. The experiment of solar PV/T-air dual heat source composite heat pump system

3.1 The introduction of experimental system

The water in the heating tank was heated by a 1 hp heat pump. The rated amount of heat exchange of the condenser was 3 kW, and R22 was used as refrigerant. Cooling parts used fan coil unit (FP-34). Two solar PV/T collectors with a size of 1580mm×808mm×35mm were used in the solar PV/T system, and the peak power of each collector was 195 W. The total collecting area and PV power generation area were 2.56 m² and 2.25 m², respectively. The power generated from solar PV/T collector was directly consumed by the rheostat. The collecting water tank capacity of solar PV/T collecting circulation system was 64L, along with heating water tank capacity of 80 L.

When the solar PV/T-air dual heat source composite heat pump system was operated, Valve 1 and valve 2 and valve 5 were open while valve 3 and valve 6 and valve 7 were closed until the temperature in the heating tank achieved 45°C or more. Then, closed valve 5 and opened valve 6 and valve 7. Fan coil unit would consume heat from the heating tank, which would ensure operational integrity of composite heat pump system.

3.2 Performance evaluation

The instantaneous thermal gain of the PV/T collector is calculated as follows:

$$W_{c,\tau} = q_{w,\tau} C_p (T_{out,\tau} - T_{in,\tau}) \quad (1)$$

Where $W_{c,\tau}$ is collecting-heat capacity and $q_{w,\tau}$ is flow, C_p is specific heat capacity, $T_{out,\tau}$ and $T_{in,\tau}$ is the outlet and inlet water temperature.

The instantaneous thermal efficiency of the PV/T collector is calculated as follows:

$$\eta_{c,\tau} = \frac{W_{c,\tau}}{A_c G_{t,\tau}} \quad (2)$$

Where A_c is collecting area and $G_{t,\tau}$ is solar irradiance.

The instantaneous photoelectric efficiency of the PV/T collector is calculated as follows:

$$\eta_{e,\tau} = \frac{W_{e,\tau}}{A_e G_{t,\tau}} \quad (3)$$

Where $W_{e,\tau}$ is generating capacity and A_e is generating area.

Instantaneous heat capacity of heat pump is calculated as follows:

$$Q_{l,\tau} = q_{l,\tau} c_p (T_{hout,\tau} - T_{hin,\tau}) \quad (4)$$

Where $q_{l,\tau}$ is flow rate, $T_{hout,\tau}$ and $T_{hin,\tau}$ are the outlet and inlet water temperature.

Instantaneous COP of heat pump is calculated as follows:

$$COP_\tau = Q_{l,\tau} / W_{p,\tau} \quad (5)$$

Where $W_{p,\tau}$ is power consumption of compressor.

4. Test results and analysis

The data tested on Jan.11, 2015 was used to evaluate solar PV/T-air dual heat source composite heat pump system performance. The test time was from 9:27am to 16:00pm. The cooling circulation system opened at 10:13am when water temperature in the heating tank was about 47°C. Fig.3 shows that ambient temperature and solar irradiance change with operating time. Ambient temperature varied between 5°C and 7.8°C, with an average value of 6.5°C. The maximum solar irradiance was 753 W/m² and the minimum was 192 W/m², with a mean value of 581.5 W/m².

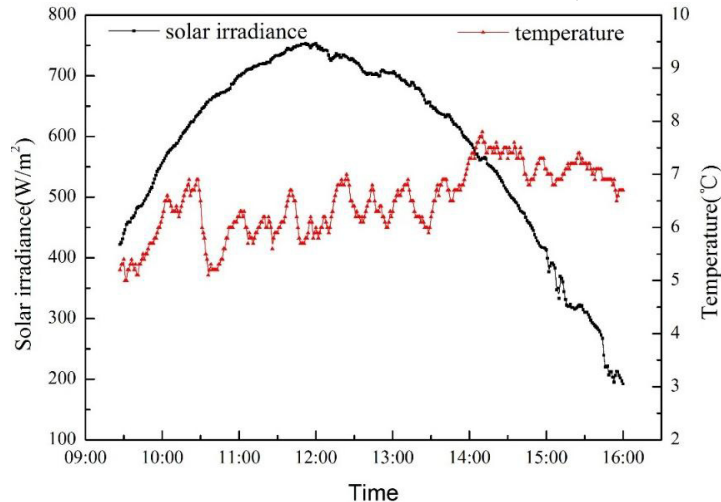


Fig. 3. Ambient temperature and solar irradiance

Fig.4 shows that electric gain and photoelectric efficiency change with operating time. Electric gain had the same trend line of change with solar irradiance show as Fig.3. The electric gain ranged from 25.0W to 239.0W, with a mean value of 174.0W. Photoelectric efficiency increased gradually in the initial operation, and almost remained unchanged when it got a constant value, later had a decrease trend after 14:00pm, which may be attributed to the relationship of photoelectric efficiency with solar irradiance and ambient temperature. The ambient temperature was

relatively low and solar irradiance played a major role in influencing the efficiency when the system began to run, so photoelectric efficiency had an increasing trend. Then photoelectric efficiency with the rising of ambient temperature fluctuated in a small range under interaction of ambient temperature and solar irradiance. Solar irradiance reduced while ambient temperature still had an increasing trend after 14:00pm, which caused photoelectric efficiency presenting a downtrend. Photoelectric efficiency changed between 5.1% and 15.0% with a mean value of 12.7% during the system operation.

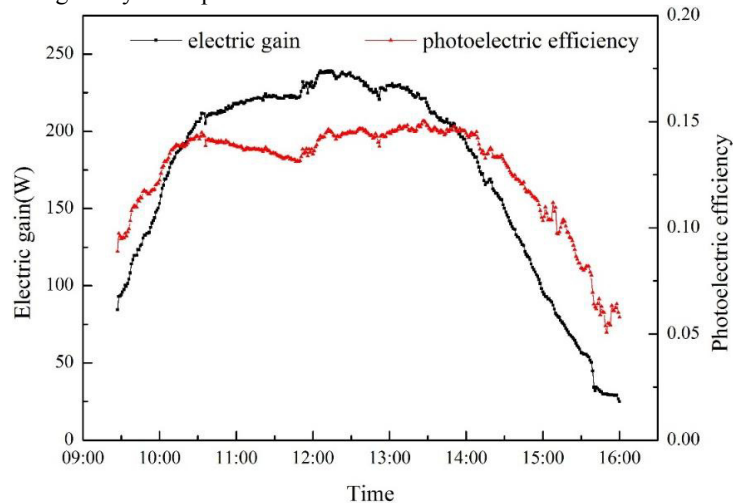


Fig. 4. Electric gain and photoelectric efficiency

Fig.5 shows that heat-collecting capacity and heat-collecting efficiency change with the operation time. The changed trend of heat-collecting capacity was basically in agreement with solar irradiance shown in Fig.3, and the value achieved the maximum when solar irradiance was the largest. The heat-collecting capacity of solar PV/T collection circulation varied between 235.2W and 844.2W, with a mean value of 639.1W. Heat-collecting efficiency changed between 27.2% and 64.0%, with an average value of 43.8% during running. A conclusion can be drawn that daily heat-collecting efficiency was relatively high.

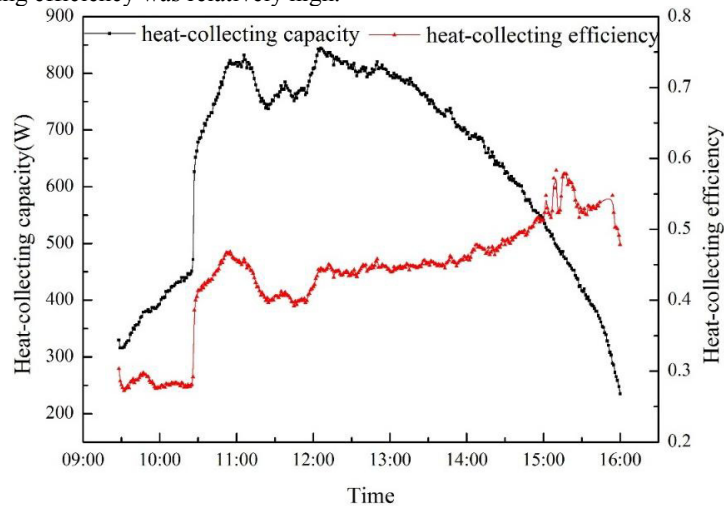


Fig. 5. Heat-collecting capacity and heat-collecting efficiency

Fig.6 shows that heat capacity of heat pump and heat release of fan coil unit vary with running time. The trend of heat capacity presented negative correlated to that of heat release. When the fan coil unit began to run, heat release gradually dropped with the extension of running time for higher water temperature in the heating tank and larger temperature difference between the water and the ambient temperature. Then heat release was basically unchanged when water temperature in the heating tank represented a stable status. Heat release of fan coil unit changed between 1.61kW and 2.34 kW, with a mean value of 1.88 kW. Heat capacity was in the range of 1.62 kW to 2.04 kW, with an average value of 1.91 kW. A conclusion can be drawn that heat release of fan coil unit and heat capacity of heat pump were in a basic balance, which indicated that cooling part and heat pump had a reasonable match.

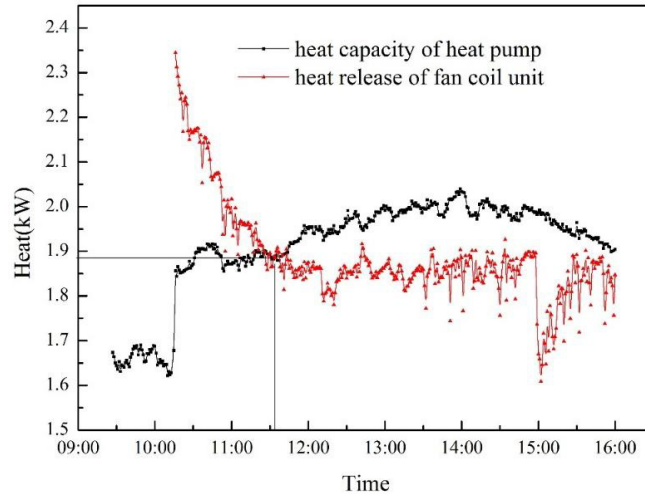


Fig. 6. Heat capacity of heat pump and heat release of fan coil unit

COP of heat pump variation is shown in Fig.7. COP had a downtrend with the rising of water temperature in the heating tank before opening the fan coil unit, then COP gradually increased under the comprehensive function of the rising of heat release and solar irradiance and ambient temperature. After 14:00pm, though ambient temperature had a rise trend, heat release and solar irradiance gradually reduced, which lead to low COP. The maximum value of COP was 2.6 and the minimum was 2.0, with a mean value of 2.5 during the running, which indicated that the system had a good performance (Wang et al.2014).

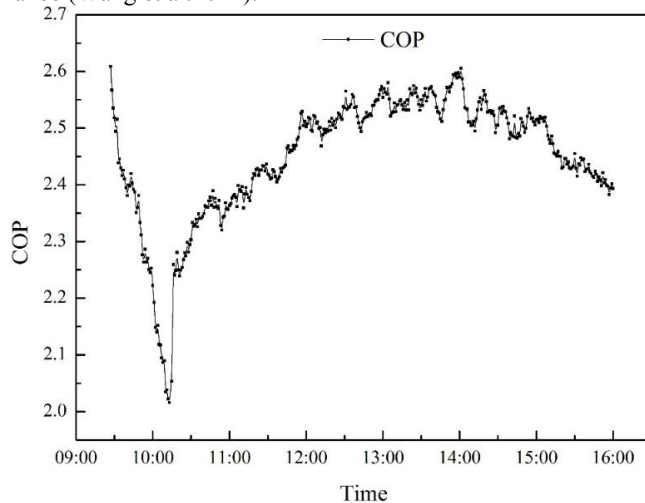


Fig. 7. COP of heat pump

Energy analysis is shown in Fig.8. Heat capacity of heat pump is equal to the sum of heat absorbed by refrigerant from air and low-temperature water of solar circulation system and power consumption of heat pump according to the law of conservation of energy. The inputs were 0.25kW much more than the outputs, which was called heat loss of the system. The heat loss was mainly due to the reason that the piping of solar circulation system and heat pump circulation system was longer and impossible to have complete thermal insulation. Heat loss rate was defined in the paper and was equal to the ratio of the inputs and outputs difference and the inputs, and it was about 11.4%. Fig.9 shows heat distribution ratio of system. Heat distribution ratio of solar, air and compressor were 28.1%, 35.7% and 36.2%, respectively.

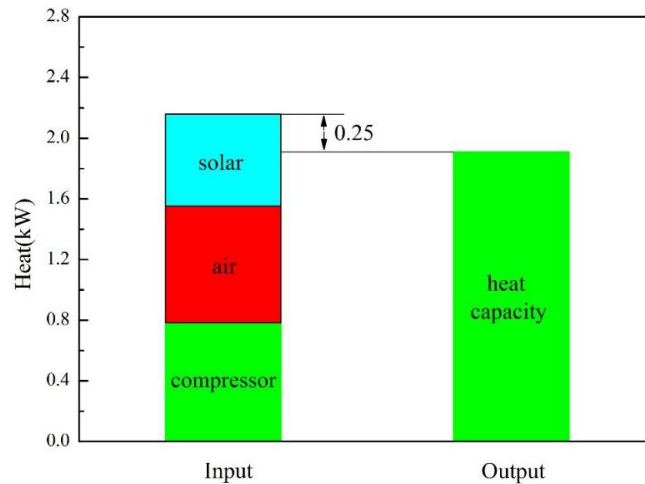


Fig. 8. Energy analysis

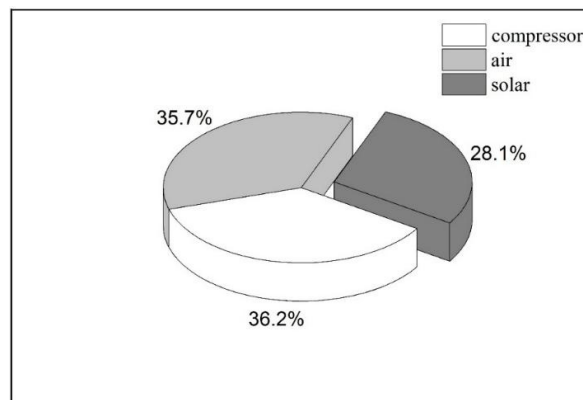


Fig. 9. Heat distribution ratio of composite heat pump

5. Conclusion

- (1) Electric gain and heat-collecting capacity of solar PV/T circulation system varied between 25.0W and 239.0W, 235.2W and 844.2W respectively. The daily photoelectric efficiency and heat-collecting efficiency were 12.7% and 43.8%, respectively.

- (2) Heat release of fan coil unit was in the range of 1.61kW to 2.34kW, with a mean value of 1.88kW. Heat capacity of heat pump changed between 1.62kW and 2.04kW, with an average value of 1.91kW. So heat release of fan coil unit was basically equal to heat capacity of heat pump and cooling component could match very well.
- (3) COP of heat pump system varied 2.0 and 2.6, with a mean value of 2.5. Simultaneously heat loss rate of system was 11.4% according to the law of conservation of energy.
- (4) Known from the experimental results, the solar PV/T-air dual heat source composite heat pump system could effectively improve the photoelectric efficiency and fully used waste heat generated by PV cells as low-temperature heat source of heat pump, which could improve the comprehensive utilization of energy. The system has a good value for extension and application.

Acknowledgement

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